MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO DE PESQUISAS ESPACIAIS

AUTORIZAÇÃO PARA PUBLICAÇÃO
AUTHORIZATION FOR PUBLICATION

PALAVRAS CHAVES/KEY WORDS (AUTORES/AUTHORS)

SÃO PAULO METROPOLITAN AREA
REMOTE SENSING
ENVIRONMENTAL IMPACT

AUTORIZADA POR/AUTHORIZED BY

Marco Antonio Raupp
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DISTRIBUIÇÃO/DISTRIBUTION

- ☐ INTERNA / INTERNAL
- ☒ EXTERNA / EXTERNAL
- ☐ RESTRITA / RESTRICTED

REVISADA POR / REVISED BY

Maria de Lourdes Kurkdijian

CDU/UDC

528.831:771.4(815.6)

DATA/DATE

August, 1988

PUBLICAÇÃO Nº
PUBLICATION NO

INPE-4670-PRE/1370

ORIGEM
ORIGIN

COT

PROJETO
PROJECT

-

Nº DE PAG. / NO OF PAGES	ULTIMA PAG. / LAST PAGE
10	09

VERSÃO / VERSION	Nº DE MAPAS / NO OF MAPS
-	-

TÍTULO/TITLE

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RESUMO-NOTAS/ABSTRACT-NOTES

Satellite-borne remote sensing data are useful for urban environment analysis owing to their improved spatial, spectral and radiometric resolution. The present study assesses the environmental impact of urban growth on the Western São Paulo Metropolitan Area from 1975 to 1985. Multidate digital data from MSS/LANDSAT, TM/LANDSAT and HRV-SPOT were registered and urban structure changes with that period was detected. Color composite photograph of TM band 5, 3 and 4 were applied to map the urban land use for new urban areas. HRV-SPOT panchromatic data, digitally enlarged to the scale of 1:10.000, were applied to urban structure mapping and environmental monitoring. Ground truth data collection and helicopter-borne data collection were used to complement the remote sensed data. Several environment degradation levels were determined and compared to the "Physical Aptitude for Urban Settlement Chart". The results showed that environmental impacts are more related to the pattern of urban settlement than to the physiographic features. Vegetative cover proved to be the most important key, indicating environmental change as far as orbital remote sensing is concerned. Soil erosion is caused by the removal of vegetative cover, but the erosion rates are controlled by the different patterns of land use.

OBSERVAÇÕES/REMARKS

Paper accepted for publication in the "16th Congress of International Society for Photogrammetry and Remote Sensing", July 1-10, 1988. Kyoto, Japan.

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ABSTRACT

Satellite-borne remote sensing data are useful for urban environment analysis owing to their improved spatial, spectral and radiometric resolution. The present study assesses the environmental impact of urban growth on the Western São Paulo Metropolitan Area from 1975 to 1985. Multidate digital data from MSS/LANDSAT, TM/LANDSAT and HRV-SPOT were registered and urban structure changes with that period was detected. Color composite photograph of TM band 5, 3 and 4 were applied to map the urban land use for new urban areas. HRV-SPOT panchromatic data, digitally enlarged to the scale of 1:10.000, were applied to urban structure mapping and environmental monitoring. Ground truth data collection and helicopter-borne data collection were used to complement the remote sensed data. Several environment degradation levels were determined and compared to the "Physical Aptitude for Urban Settlement Chart". The results showed that environmental impacts are more related to the pattern of urban settlement than to the physiographic features. Vegetative cover proved to be the most important key, indicating environmental change as far as orbital remote sensing is concerned. Soil erosion is caused by the removal of vegetative cover, but the erosion rates are controlled by the different patterns of land use.

1. INTRODUCTION

Discussions concerning the environment in Brazilian metropolitan areas currently subjected to intense urbanization are part of the problematics of natural resource degradation and environmental impacts, which have become a matter of growing and generalized concern. The negative effects of human interaction with natural systems are more intensely visible in spaces of elevated population concentration, as is the case for densely settled metropolitan areas.

The objective of the present investigation was to evaluate some environmental impacts such as those caused by degradation of vegetation and increased soil erosion due to the intensive occupation of the Western São Paulo Metropolitan Area during the period from 1975 to 1985. A dynamic analysis of the alterations that have occurred was performed using remote sensing data and techniques in addition to available supporting data.

Several physical, social and economic aspects were considered in order to evaluate the interference of human settlement with

environmental conditions. The main objectives of this study were:

a) to evaluate the environmental changes that have occurred in the Western São Paulo Metropolitan Area from 1975 to 1985 using remote sensing data and techniques, and

b) to evaluate the vegetative cover index as an indicator of urban life quality.

Environmental changes were assessed with a multitemporal approach and a few specific objectives were defined:

- identification of areas of urban expansion and of the structuring of new areas incorporated into the urban tissue;
- identification of the environmental components that can be monitored by orbital remote sensing systems;
- evaluation of the importance of elements indicating changes in the environmental equilibrium;
- evaluation of the extent of environmental change that has occurred in the area under study in view of the intense urban-industrial settlement during the period under analysis;
- evaluation of MSS, TM-LANDSAT and HRV-SPOT data for the study of urban systems.

2. SÃO PAULO METROPOLITAN AREA

Estimates by the Collection and Analysis Center (CCA) indicate that São Paulo Metropolitan Area has 15,087,712 inhabitants, with a population density of 1,897 inhabitants/km² (EMPLASA, 1986). Whatever the indicator used to illustrate the position of the São Paulo Metropolitan Area from a social, economic or urban viewpoint, the fundamental importance of the Area will be perceived immediately both in terms of its opulence and greatness and in terms of its problems and shortcomings (EMPLASA, 1982; Niero et al., 1982; Kowarich and Campanário, 1985).

The vigorous industrial development that occurred in the area starting in the 1950s has triggered a process of urban settlement that has reserved the central and better equipped areas for the strata of medium and high acquisitive power and has segregated the working class to the distant and rarefied periphery of the metropolis, especially around the major railroads and highways. This settlement pattern has caused an accelerated growth that has multiplied by nine the original "urban spot" over the last three decades (Kowarich and Campanário, 1985).

Several factors have combined to turn today's São Paulo Metropolitan Area a true laboratory for the study of all areas of interest because of the diversity and complexity of the problems involved. After becoming the most important industrial and economic complex in Latin America, São Paulo has spread its influence beyond national boundaries, showing the highest rates of industrial, population and urban growth over the last three decades.

After World War II the city of São Paulo and surrounding area have expanded at a rate that definitely consolidated the metropolization process which has started in the 1930s, with the population increasing from 1.6 millions in 1940 to 2.7 millions in 1950, 4.8 millions in 1960, 8.2 millions in 1970 and 12.7 millions in 1980.

According to Ab'Saber (1976), the São Paulo Metropolitan Area has acquired an urban conformation and metropolitan structure showing sharply contrasting and practically unique aspects among the large cities in today's world because of the sheer spatial and demographic volumes involved. The city which grew through a plan of tentacular type, later evolved towards a gigantic tentacular-nebular scheme of a semi-caotic type owing to the addition of lower-class residential neighborhoods over the last 30 years (1945-1975). The process of metropolization started as the result of a first industrialization phase (1900-1930); supported by external migratory currents and by the extravasation of capital amassed during the coffee cycle and invested in industrial activities.

The continuous growth of the nucleus of the São Paulo Metropolitan Area from the end of the last century to our days has provoked the successive incorporation of new areas into the urban tissue, creating with time a gigantic city that overflows the municipal boundaries. Since 1930, the continuous urban area has increased approximately 9-fold: only in the decade of 1970, approximately 480 km^2 were incorporated into the area (EMPLASA, 1982).

Another problem related to the disorderly expansion of the metropolitan area concerns the environmental impacts created by expansion on surfaces whose declivities are incompatible with urbanization. The accelerated expansion of the São Paulo Metropolitan Area impairs the continuous monitoring of the environmental and structural changes of the urban space. The decision-making process of urban-planning agencies is also impaired by the difficulty of obtaining up-to-date information about urban dynamics. New and adequate methods and techniques are needed to study urban expansion and environmental changes within a short period of time for greater effectiveness on the part of the planning agencies. Thus, in the present paper we present a sequence of methodological procedures for the study of the environmental impact caused by urban expansion in the São Paulo Metropolitan Area, based on the analysis of remote sensing data.

3. MATERIAL AND METHOD

We present a methodological sequence for the use of remote sensing data at different observation levels and scales (Foresti, 1986). The methodology is based on the observation of data referring to a 10-year period (1975 to 1985) and the use of MSS and TM-LANDSAT, HRV-SPOT products, as well as panchromatic aerial photographs, helicopter-borne data and field data. MSS-LANDSAT data obtained every two years were used to monitor the expansion

of the continuous urban area in the São Paulo Metropolitan Area from 1975 to 1985.

The objective of this stage in the project was to define within the limits of our possibilities a biennial rate of urban growth by estimating the new areas incorporated into the urban tissue of the São Paulo Metropolitan Area during the following years: 1975, 1977, 1979, 1981, 1983 and 1985.

The experimental area to be studied (The Western São Paulo Metropolitan Area) was selected on the basis of analysis of a period of 8 years, 1976 to 1986, in which the results of the delimitation of the continuous urban area of the São Paulo Metropolitan Area obtained at the two dates in question were superimposed. This permitted us to identify a sector in which urban growth is occuring in an intensive manner and which deserves a more detailed assessment of the environmental impact provoked by urban expansion. For the purposes of this study, the Western São Paulo Metropolitan Area is partially formed by the municipalities of Osasco, Carapicuiba, Barueri, Itapevi, Jandira and Santana do Parnaíba.

Multitemporal analysis of orbital data was done for the experimental area by the semi-automatic image-recording technique with IMAGE-100. This technique permits visualizing on the video of the IMAGE-100 system a multitemporal color composition in which cyan an red are combined for the older and more recent dates, respectively. In the color composition, the blue areas represent targets that were urban areas and/or exposed soil during the first passage and which were occupied by vegetation in the second passage. Red areas are those that showed vegetative cover during the first passage and urban occupation and/or exposed soil during the second.

This color key permitted us to identify the areas of urban expansion in a rapid manner. The precision of the map and the sites of soil use were checked in the field by visiting 50 sities and plotting them on the topographic maps at the scales of 1:50,000 and 1:25,000.

Nine major types of soil use were defined for the altered areas:

1 - urbanized areas: densely built residential areas;
2 - residential agglomerations: areas built in the intraurban spaces;
3 - industries: extensive areas of industrial occupation or isolated industries;
4 - empty developments: developments with street zoning but no construction;
5 - partially settled developments: developments with construction under way;
6 - landfill: landfilled areas for industrial or residential use;
7 - earth moving: abandoned mineral extraction areas; loan boxes, etc.;

8 - expansion of quarries;
9 - deforested areas.

The magnitude of the altered areas was assessed by helicopter surveys.

The altered areas of urban expansion were also analyzed on the basis of the color composition obtained by the combination of spectral bands 5, 3 and 4 of the TM-LANDSAT sensor, respectively associated with the colors blue, green and red. This combination of TM channels proved to be the most appropriate for this study and permitted the separation of homogeneous areas of urban settlement on the basis of textural arrangements and variations in tonality. Thus, densely built areas are readily visible as blue and smooth-textured tones. Recently opened developments, landfills areas and areas of typical industrial use are visualized as light-colored tones (tending to white) mainly because of the spectral contribution of soil, and the same applies to landfill areas with no vegetative cover. Large urban targets, and industries in particular, are also well-defined in this type of color composition.

Panchromatic HRV-SPOT sensor data were used for in-depth analysis of urban structuration. A few typical areas of urban settlement were selected for detailed mapping of the urban environment after digital enlargement of HRV-SPOT panchromatic data to a scale of 1:10,000, with 10m spatial resolution. Detailed analysis of these segments consisted of the determination of vegetative cover indices by aerial photography, of vegetation indices from orbital data and of evaluation of the location of these areas in relation to the classes of physical aptitude for urban settlement defined by EMPLASA (1986). Overall analysis of the data obtained from orbital images, aerial photographs and field data permitted us to classify the area of urban expansion into three levels of soil degradation with respect to the erosion process: DL, low degradation; DM, medium degradation- Dh, high degradation. The definition of these three levels of soil degradation was qualitative in nature and was valid for the area studied, since it resulted from the verification of how the environment is responding to antropic interference in the areas of urban expansion. The degradation levels were determined on the basis of the presence of laminar erosion, ravine formation and furrowing.

4. RESULTS

4.1 - Urban Growth in the Western São Paulo Metropolitan Area from 1975 to 1985

Urban growth in the Western São Paulo Metropolitan Area was assessed in 1975, 1979 and 1985. The greatest expansion occured between 1975 and 1979, with approximately 33% variation in total area. Many areas destined to industrial use were landfilled during this time (1975 - 1979) and field inspection showed that they had not yet been occupied by industries. The urban area of Western São Paulo was approximately 150 km² in 1985 with 13% expansion in relation to 1979. Thus, it can be seen that the

rate of urban expansion, which was 33% from 1975 to 1979, tended to slow down from 1979 to 1985.

4.2 - Detailed analysis of areas that changes in the Western São Paulo Metropolitan Area

Multitemporal analysis of land use from 1976 to 1984 by the image-recording technique permitted the identification and localization of the areas that changed during this period. A few segments were digitally enlarged to the scale of 1:10,000 to permit the visualization of changed areas and the qualitative assessment of the urban environment. In addition to the evaluation of the expansion and structuration or urban space, this technique also permitted the analysis of environmental impacts related to urban expansion.

The removal of the vegetative cover for the construction of large building complexes proved to be the factor triggering soil erosion, and the vegetative cover indices obtained indicated different levels of degradation processes according to different parameters such as relief and raining patterns. Urbanized areas showed both high and low indices of vegetative cover during settlement. For example, when upper class residential neighborhoods are first developed, the vegetation is totally removed (0.0 to 0.3 indices) in most cases, but very high vegetation indices (0.6 to 0.9) are observed after the final phase of settlement. In lower class residential developments, the vegetation is not always totally removed during the initial phase. As construction progresses, however, high residential agglomeration occurs and the vegetative cover shows very low indices.

Industrial areas show very low vegetative cover indices both during the initial phase of construction and at the time of full functioning. In constrast, country club-style residential areas maintain high indices throughout all phases, from implantation to actual urban settlement. When the vegetation is removed and the area is covered with constructions, gardens, trees, etc., during the process of urban settlement, the process of soil degradation is interrupted. Thus, the removal of vegetation alone does not necessarily imply soil degradation.

The results of the present study involving observations in the field and by helicopter showed that the environmental degradation of the Western São Paulo Metropolitan Area is much more related to the economic aspect of project implantation than to the favorable physical characteristics of the area.

5. EVALUATION OF THE VEGETATION INDEX AS AN INDICATOR OF URBAN LIFE QUALITY

Today there is general agreement about the important role of vegetation in urbanized areas. Monteiro (1976) pointed out the importance of green areas from an esthetic viewpoint and also as leisure areas and as regulatory valves of rainwater drainage

in large urban settlements. Lombardo (1985) reported on the thermal comfort provided by green areas and emphasized the need for legislation about the use of metropolitan soil, with reservation of interstitial green spaces in peripheral neighboorhoods to be developed.

Lenco et al. (1982), Delavigne et al. (1982), and Delavigne and Thibault (1984) have suggested that the vegetation index obtained from orbital data be used for the direct assessment of vegetation density in built areas, and for an estimate of arborization in relation to constructed area. According to these authors, the vegetation index can be considered as an indicator of the quality of life in the urban environment and could be one of the parameters used in the definition of the urban ecosystem.

The present results showed that the Western São Paulo Metropolitan Area for the most part has high vegetation indices, with 87.08% of the area under study showing vegetative indices higher than 106, which represents high vegetation density. Results obtained by Foresti and Pereira (1986) for the central São Paulo area have permitted a classification coherent with the urban quality of the various segments identified for that urban sector. This leads us to assume that for an urban area or a given sector in which the other variables are controlled, a relative identification of areas with variations in urban life quality can be made on the basis of vegetation index.

The Western São Paulo Metropolitan Area does not have adequate basic sanitation conditions. Since it is difficult to assess the quality of urban life simply on the basis of vegetation index, other elements of the urban structure need to be considered for a better evaluation of the living conditions of the various sectors of urbanized areas.

6. CONCLUSIONS

In view of the initial objectives the results of the present research led us to the following conclusions:

- The expansion of the São Paulo Metropolitan Area has been following the main highways, more markedly so in the SW and NE directions. The results of the present study show a slow-down in the rate of urban expansion since 1979.

- Monitoring urban expansion on the basis of remote sensing data and techniques proved to be the method best suited to this type of study. The new sensors available today (TM and HRV) are the most indicated for urban studies.

- The semi-automatic image recording technique based on digital processing proved to be an adequate tool for the assessment of environmental changes in the Western São Paulo Metropolitan Area.

- The assessment of vegetative index as an indicator of urban life quality has shown that this is an efficient tool when the basic sanitation infrastructure (water, light, sewage, health, schools, etc.) is standardized. At the periphery of São Paulo, in general this index is difficult to use as an indicator of urban life quality.

- The environmental impacts of the Western São Paulo Metropolitan Area are more related to conditions of urban settlement patterns than to the physical characteristics of the area under study.

- The vegetative cover proved to be the most important indicator of changes in environmental equilibrium, which could be monitored using orbital remote sensing systems. Removal of the vegetative cover triggers soil erosion, but this process can be accelerated or interrupted according to the pattern of use of the area involved.

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